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A TECHNICAL ASSESSMENT OF CURRENT WATER QUALITY CONDITIONS AND FACTORS AFFECTING WATER QUALITY IN THE UPPER POTOMAC ESTUARY

Norbert A. Jaworski, et al

Federal Water Pollution Control Administration
Annapolis, Maryland

March 1969

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Technical Report No. 5
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A TECHNICAL ASSESSMENT

OF

CURRENT WATER QUALITY CONDITIONS

AND

FACTORS AFFECTING WATER QUALITY

IN THE

UPPER POTOMAC ESTUARY

March 1969

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Technical Report No. 5
Chesapeake Technical Support Laboratory
Middle Atlantic Region
Federal Water Pollution Control Administration
U. S. Department of the Interior

57

10

TABLE OF CONTENTS

		Page
LIST OF TABLES		iv
LIST OF FIGURES		v
Chapter		
I	INTRODUCTION	I- 1
II	CURRENT WATER QUALITY CONDITIONS	II - 1
	A. Fecal Coliform Densities	II - 1
	B. Dissolved Oxygen (DO)	II - 4
	C. Biochemical Oxygen Demand (BOD)	II - 6
	1. Sources of BOD	II - 6
	2. BOD Concentrations in the Estuary	II - 6
	D. Nutrients - Phosphorus and Nitrogen	II - 10
	1. Sources of Nutrients	II - 10
	2. Nutrient Concentrations in the Estuary	II - 14
	E. Algal Standing Crop	II - 17
III	NUTRIENT-ALGAL RESPONSE AND ENVIRONMENTAL REQUIREMENTS	III - 1
	A. Phosphorus	III - 3
	B. Nitrogen	III - 5
	C. Other Considerations	III - 14
	1. Stream Flow	III - 14
	2. Temperature, Solar Radiation and Light Extinction	III - 14
	3. Other Environmental Parameters	III - 15

TABLE OF CONTENTS (Continued)

Chapter		Page
IV	ORGANIC LOADINGS IN THE UPPER AND MIDDLE ESTUARIES	IV - 1
	A. Algal Carbonaceous and Nitrogenous BOD . . .	IV - 1
	B. Wastewater Carbonaceous BOD	IV - 4
	C. Wastewater Nitrogenous BOD	IV - 5
	D. Benthic-Background Carbonaceous and Nitrogenous BOD	IV - 6
	E. Ultimate Oxygen Demand Comparison	IV - 6
	F. Dissolved Oxygen Balance	IV - 7
V	CURRENT AND PROPOSED INVESTIGATIONS	V - 1
REFERENCES		

LIST OF TABLES

Number	Title	Page
II - 1	Wastewater Loadings, Potomac Estuary Intensive Survey, August 19-22, 1968	II - 7
II - 2	Summary of BOD and Nutrient Loadings, Upper Potomac Estuary, August 19-22, 1968	II - 8
II - 3	Average Total Phosphorus Loadings As PO_4, Potomac River Basin	II - 11
II - 4	Average Total Nitrogen Loadings As N, Potomac River Basin	II - 12
II - 5	Predicted Average Monthly Nutrient Loadings, Potomac River Near Washington, D.C.	II - 13
III - 1	Nutrient-Chlorophyll Data Sources	III - 2

LIST OF FIGURES

Number	Title	Page
I - 1	Potomac Estuary	I - 2
II - 1	Fresh Water Inflow, Water Temperature, and Solar Radiation, Upper Potomac Estuary, May-October 1968	II - 2
II - 2	Fecal Coliform Isopleth, Upper Potomac Estuary, May-October 1968.	II - 3
II - 3	Dissolved Oxygen Isopleth, Upper Potomac Estuary, May-October 1968.	II - 5
II - 4	BOD Isopleth, Upper Potomac Estuary, May-October 1968	II - 9
II - 5	TKN as N Isopleth, Upper Potomac Estuary, May-October 1968	II - 15
II - 6	NO_2+NO_3 as N Isopleth, Upper Potomac Estuary, May-October 1968	II - 16
II - 7	Total P as PO_4 Isopleth, Upper Potomac Estuary, May-October 1968.	II - 18
II - 8	Chlorophyll Isopleth, Upper Potomac Estuary, May-October 1968	II - 19
III - 1	Chlorophyll - Total Phosphorus Concentrations, Summer Conditions, for Various Areas of the Chesapeake Bay System	III - 4
III - 2	Chlorophyll - Inorganic Phosphorus Concentrations, Potomac Estuary, Intensive Survey 1966	III - 6
III - 3	Nutrients and Chlorophyll, Potomac Estuary, August 19-22, 1968	III - 8
III - 4	Nutrient and Chlorophyll Loading Rates, Potomac Estuary, August 19-22, 1968	III - 9

LIST OF FIGURES (Continued)

Number	Title	Page
III - 5	Chlorophyll - Inorganic Nitrogen Concentrations, Summer Conditions, for Various Areas of the Chesapeake Bay System	III - 11
III - 6	Chlorophyll - Inorganic Nitrogen Concentrations, Potomac Estuary, Intensive Surveys 1966 and 1968.	III - 12
IV - 1	Five-Day BOD Delineation and TOC-DO Profiles, Potomac Estuary, August 19-22, 1968	IV - 2
IV - 2	A Schematic Diagram of Dissolved Oxygen Interrelationships for the Three Major Biological Systems	IV - 8

CHAPTER I

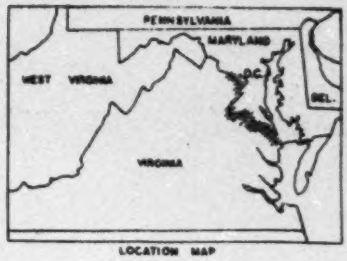
INTRODUCTION

Water quality problems in the Potomac River Basin, their sources and corrective actions required, are the subject of continuing investigations by the Chesapeake Technical Support Laboratory (CTSL)* of the Middle Atlantic Region (MAR) of the Federal Water Pollution Control Administration (FWPCA) in conformance with provisions of the Federal Water Pollution Control Act, as amended (33 U.S.C. 466 et seq.). A map of the Potomac Estuary is presented in Figure I-1.

Initially, emphasis was placed on water quality monitoring and the application and verification of mathematical models capable of simulating the effects of low-flow augmentation, wastewater diversion, water supply withdrawals and increased degrees of wastewater treatment on dissolved oxygen (DO), phosphorus, and chloride concentrations in the estuary. The use of mathematical model not only provides predictive capability for effect of future wastewater discharges in the upper Potomac Estuary but also furnishes a means of investigating biological and environmental conditions affecting dissolved oxygen.

Using the report "A Research Program for the Potomac River" by Dr. John C. Geyer, et al. [1] as a guide, studies were instituted to determine the effects of benthic deposits, nitrification and phytoplankton activity on the dissolved oxygen balance in the estuary.

*Formerly the Chesapeake Field Station



LOCATION MAP

LEGEND

- MAJOR WASTE TREATMENT PLANTS
- ESTUARY SEGMENT
- GAGING STATION POTOMAC RIVER at WASHINGTON, D.C.
- A DISTRICT OF COLUMBIA
- B ARLINGTON COUNTY
- C ALEXANDRIA SANITARY AUTHORITY
- D FAIRFAX COUNTY - WESTGATE PLANT
- E FAIRFAX COUNTY - LITTLE HUNTING CREEK PLANT
- F FAIRFAX COUNTY - DOGUE CREEK PLANT
- G WASHINGTON SUBURB SANITARY COMMISSION - PISCATAWAY

POTOMAC ESTUARY

SCALE IN MILES

FIGURE 1-1

Investigations were also made to determine sources and rate limiting concentrations of various measurable nutrients which, if controlled, could alleviate eutrophic conditions in the upper Potomac Estuary.

This report includes an assessment of the current (1968) water quality conditions and factors affecting water quality in the upper Potomac Estuary. It includes the sources and effects of the nutrients on the production of massive phytoplankton growths; and, finally, it contains an evaluation of all major sources of carbonaceous and nitrogenous BOD including wastewater discharges, benthic background, and phytoplankton growths and their effects on the DO balance.

This report is one of a series prepared by CTSL on various aspects of the water quality management in the Potomac River Basin [2] [3] [4] [5] [6] [7] [8].

CHAPTER II

CURRENT WATER QUALITY CONDITIONS

The water quality conditions in the Potomac Estuary are monitored, usually weekly, by CTSL and by the Department of Sanitary Engineering of the District of Columbia. The results of the monitoring program for the months of May through October 1968 are presented herein. The fresh water inflow, water temperature, and solar radiation for the six-month time period are presented in Figure II-1.

A. Fecal Coliform Densities

As can be seen in Figure II-2, high fecal coliform densities, over 1000 MPN/100 ml, were detected in a reach of the upper estuary from Memorial Bridge (River Mile 4.8)* to Piscataway Creek (River Mile 18.0). Fecal coliform densities over 10,000 were also detected principally in the reach between Bellevue (River Mile 9.7) and Woodrow Wilson Bridge (River Mile 11.8). The fecal coliform water quality standards for the waters of the Potomac Estuary are 240 and 200 MPN/100 ml maximum for Maryland and the District of Columbia, respectively.

In the middle reaches of the estuary below Indian Head (River Mile 29.5), the fecal coliform densities were below 10 MPN/100 ml. No routine bacterial analyses were made in the main channel of the lower estuary.

*River miles are the distances measured downstream from Chain Bridge.

II-2

FRESH WATER INFLOW, WATER TEMPERATURE, and SOLAR RADIATION

UPPER POTOMAC ESTUARY

MAY to OCTOBER 1968

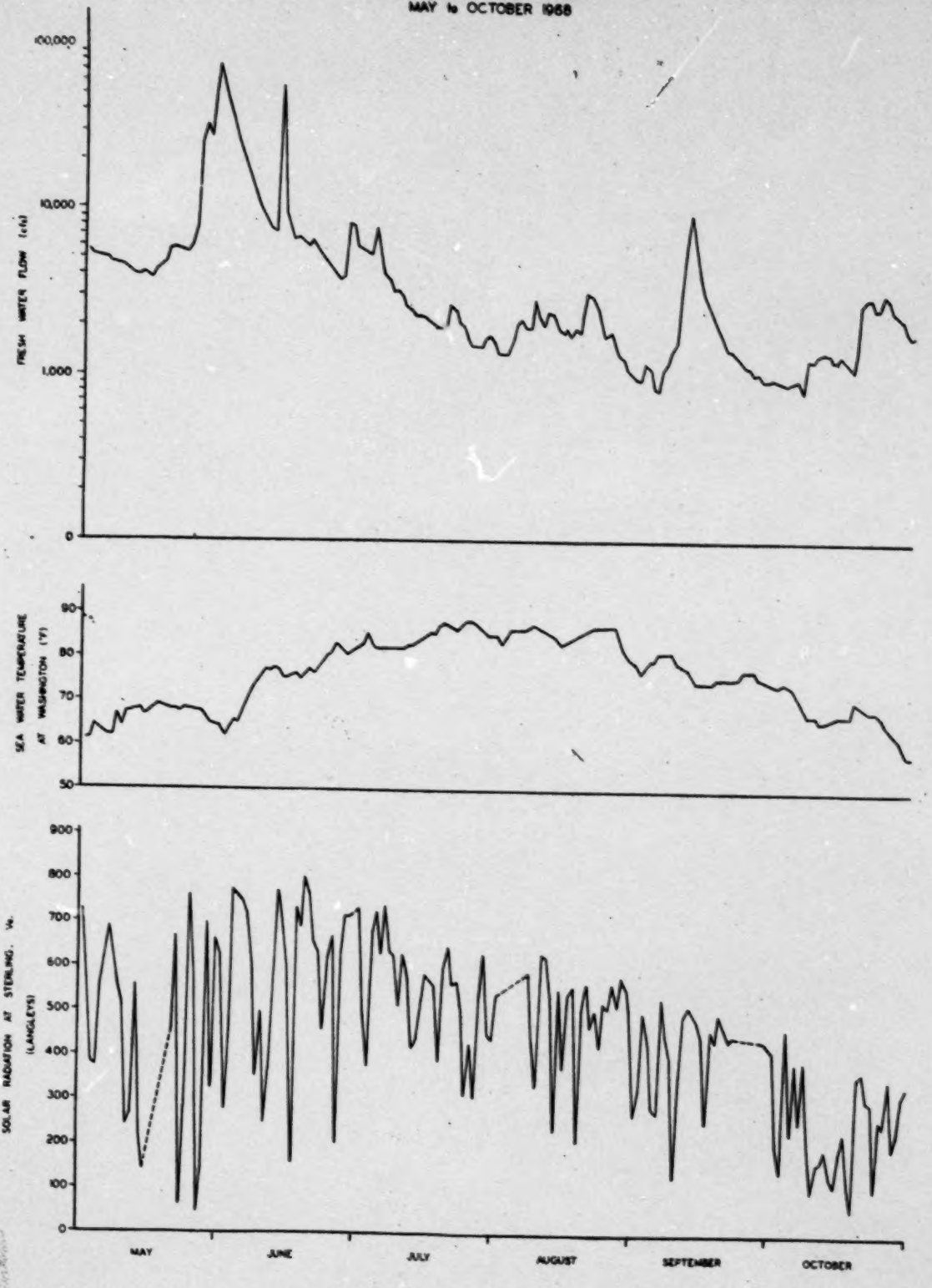


FIGURE II-1

FECAL COLIFORM ISOPLETH

(MPN/100ml)

UPPER POTOMAC ESTUARY

MAY to OCTOBER 1968

CHESAPEAKE TECHNICAL SUPPORT LABORATORY

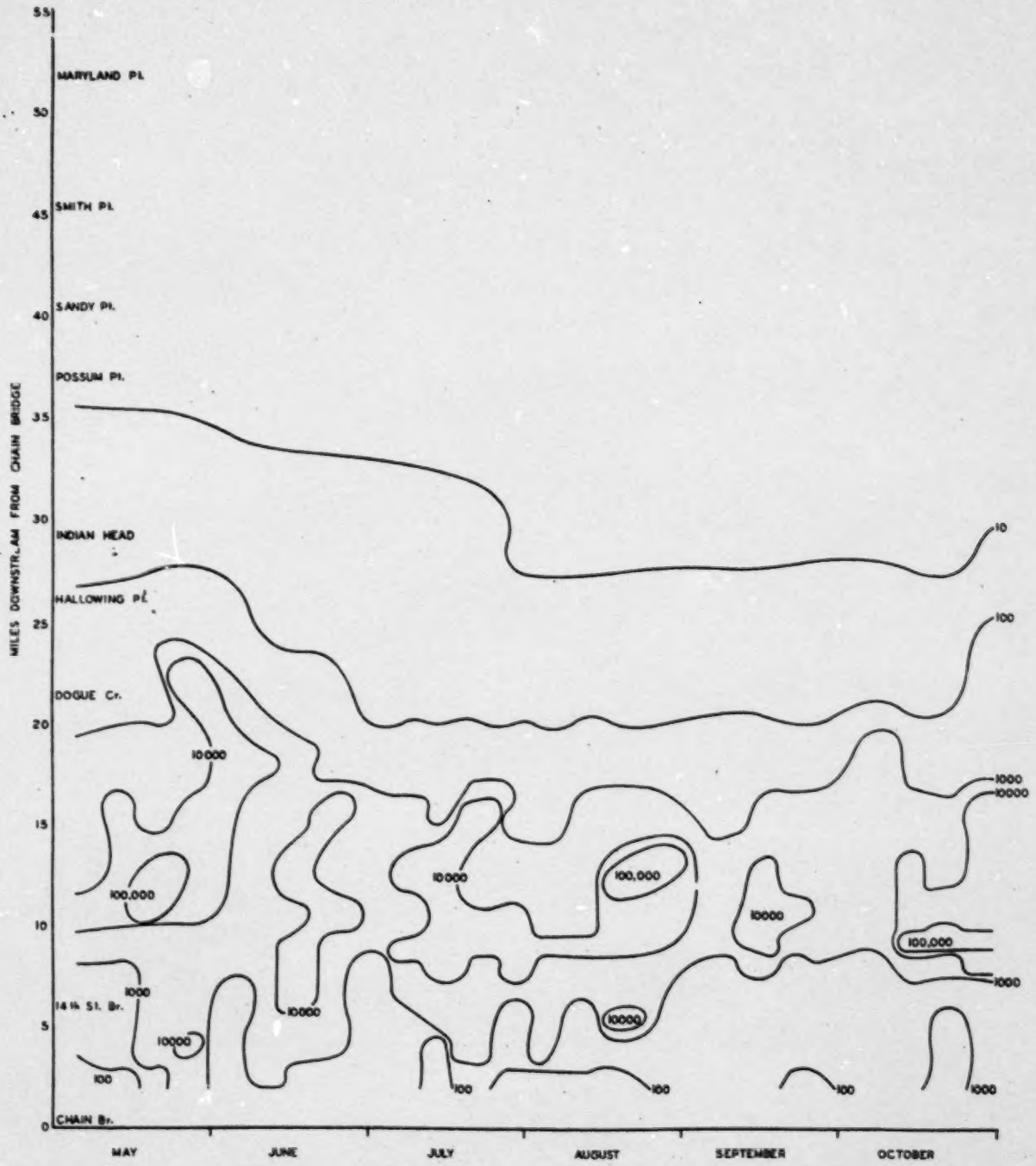


FIGURE II-2

B. Dissolved Oxygen (DO)

The dissolved oxygen levels in the estuary from Memorial Bridge (River Mile 4.8) to Hallowing Point (River Mile 26.0) were usually less than 6.0 mg/l as presented in an isopleth* in Figure II-3. During the months of July through October, when the fresh water flow into the estuary was less than 2000 cfs, the DO in the reach from Haines Point (River Mile 7.4) to Dogue Creek (River Mile 22.4) often dropped below 4.0 mg/l. Periods of less than 2.0 mg/l dissolved oxygen concentration were observed in the reach from Haines Point to Broad Creek. The DO water quality standards for the waters of the upper Potomac Estuary are an average of 5.0 and 4.0 mg/l for Maryland and the District of Columbia, respectively.

In the upper part of the estuary near Fletcher's Boat House (River Mile 2.0), the DO was usually 8.0 mg/l and greater. Generally, dissolved oxygen concentrations between 6.0 and 8.0 mg/l were detected in the middle part of the estuary from Indian Head to the Route 301 Bridge (River Mile 67.5)..

*An isopleth, which exhibits a complete graphical presentation of water quality with respect to location and time along the estuary, is useful for depicting variations of a parameter at a given location for a specific time or for a given time period along the estuary. The isopleths were constructed by plotting all data for a given station along the estuary for the six-month period. A smooth curve was fitted to these data as representative of "average" conditions during the entire survey period.

DISSOLVED OXYGEN ISOPLETH

(mg/l)

UPPER POTOMAC ESTUARY

MAY to OCTOBER 1968

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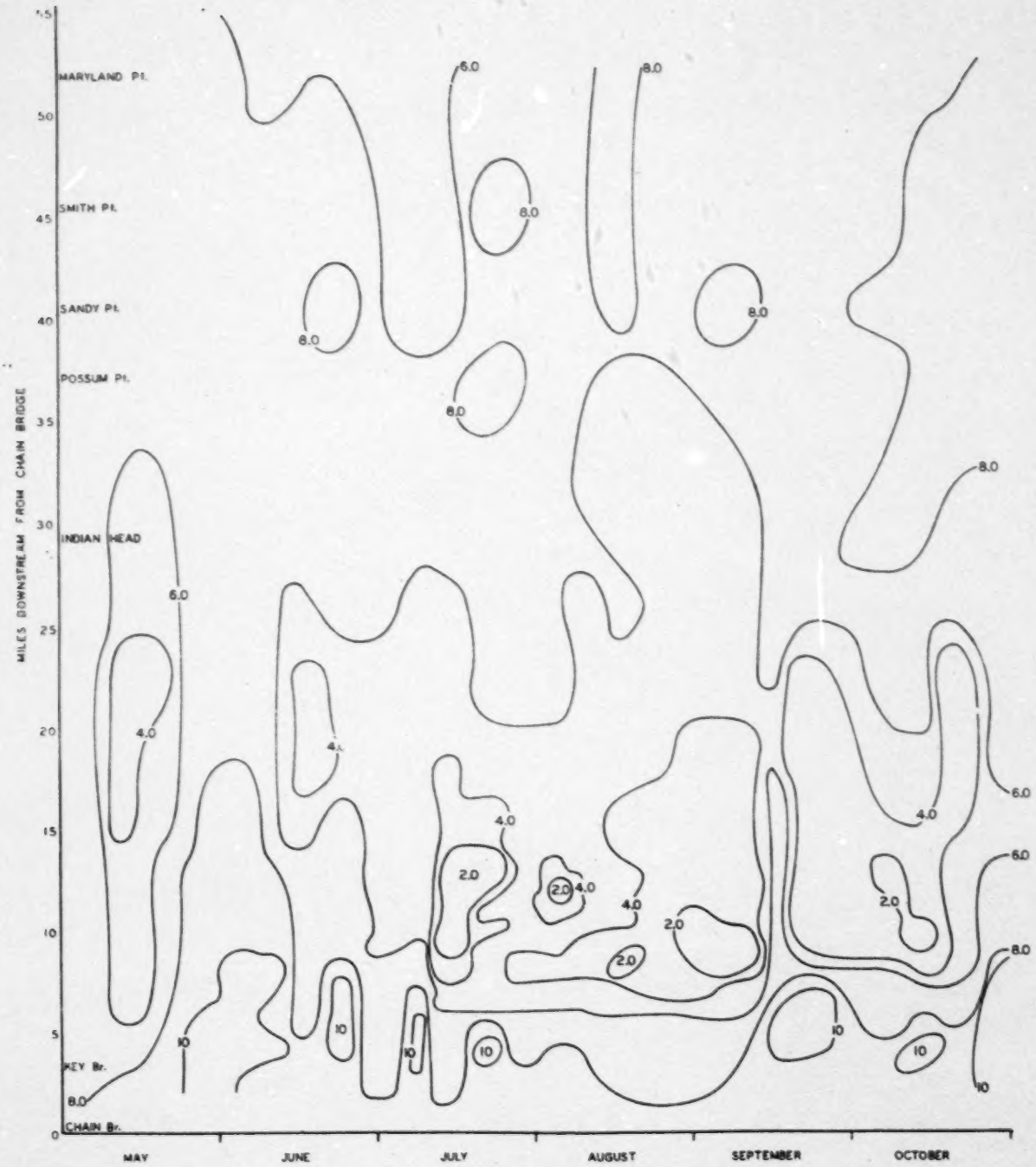

FIGURE II-3

C. Biochemical Oxygen Demand (BOD)

1. Sources of BOD

The four principal sources of BOD in the estuary are:

a. Wastewater - carbonaceous,

b. Wastewater - nitrogenous,

c. Algal - carbonaceous and nitrogenous, and

d. Benthic-background - carbonaceous and nitrogenous.

The carbonaceous and nitrogenous BOD,* including nutrients from the wastewater discharges, were routinely monitored by the personnel of the various treatment facilities and were intensively sampled during the special surveys of August 19 to 22, 1968, and February 11 to 13, 1969, by CTSL. A tabulation of the wastewater treatment plant BOD and nutrient loadings for the August 1968 survey is presented in Table II-1. A summary of BOD and nutrient loadings from wastewater discharges and the fresh water inflow for the August 1968 survey is presented in Table II-2.

2. BOD Concentrations in the Estuary

In the reach from Chain Bridge (River Mile 0.0) to Piscataway Creek (River Mile 18.0), the BOD concentrations were increased from an average of 3.0 mg/l to over 10.0 mg/l and greater at times by wastewater discharges (Figure II-4). The high BOD level in the reach from Piscataway to Indian Head was due primarily to algal carbon. This will be discussed later in this report.

*BOD is 5-day BOD at 20°C unless stated otherwise.

Table II - 1

WASTEWATER LOADINGS
Potomac Estuary Intensive Survey
August 19-22, 1968
Chesapeake Field Station

Treatment Facility	Population Served	Flow	BOD		S. Solids		TKN as N		TPO_4 as PO_4		NH_3 as N	TOC
		(mgd)	Untreated (#/day)	Treated (#/day)	Untreated (#/day)	Treated (#/day)	Untreated (#/day)	Treated (#/day)	Untreated (#/day)	Treated (#/day)	Treated (#/day)	Treated (#/day)
Pentagon	42,000	1.33	2,800	320	2,400	90	160	120	290	220	110	260
Arlington	186,000	21.30	34,000	4,100	36,000	7,300	4,600	3,400	5,700	5,300	2,100	4,300
Overflows 2.7 of D. C.	-	7.10	8,400	8,400	9,600	9,600	1,300	1,300	1,400	1,400	700	5,900
District of Columbia	1,750,000	261.00	307,000	92,000	353,000	114,000	48,000	40,000	52,000	44,000	20,000	72,000
Alexandria	180,000	19.80	31,000	8,300	30,000	7,500	4,300	3,600	5,400	4,700	2,300	6,900
F. Westgate	127,000	11.28	28,300	14,500	21,000	10,300	2,900	2,500	3,200	3,000	1,100	10,000
Piscataway	50,000	5.00	6,700	540	5,100	460	700	600	1,500	920	440	840
Andrews AFB #1	8,000	0.71	1,700	200	1,000	140	110	50	170	80	30	7[illegible]
Andrews AFB #4	1,000	0.07	180	30	70	10	10	3	20	1[illegible]	[illegible]	8
F. Hunting Creek	33,000	2.87	5,400	820	4,400	760	720	640	1,000	950	310	850
F. Dogue Creek	16,000	1.36	3,100	430	3,100	400	360	260	460	450	160	360
Ft. Belvoir #1	3,500	0.55	1,100	180	1,300	240	90	60	60	20	50	100
Ft. Belvoir #2	18,400	1.58	2,900	380	2,600	260	290	260	450	230	170	300
Total	2,414,900	334.15	428,000	130,200	469,570	151,060	63,540	52,793	71,650	61,282	27,472	101,893
Per capita/day	-	138 (gcpd)	0.177 (#cpd)	0.0521 (#cpd)	0.194 (#cpd)	0.061 (#cpd)	0.026 (#cpd)	0.021 (#cpd)	0.029 (#cpd)	0.025 (#cpd)	0.011 (#cpd)	0.042 (#cpd)

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TABLE II-2

SUMMARY OF BOD AND NUTRIENT LOADINGS
Upper Potomac Estuary
August 19-22, 1968

Parameter	Unit	Wastewater Discharges	Fresh Water* Inflow
Flow	mgd	334	1,780
BOD	lbs./day	130,000	52,800
TOC	lbs./day	101,000	87,500
TKN as N	lbs./day	52,800	14,500
NO_2+NO_3 as N	lbs./day	insignificant	1,500
NH_3 as N	lbs./day	27,500	1,800
TP as PO_4	lbs./day	61,300	4,800

* Based on flows and concentrations for Potomac River at Little Falls.

TOC = Total organic carbon
TKN = Total Kjeldahl nitrogen
TP = Total phosphorus

BOD ISOPLETH

(mg/l)

UPPER POTOMAC ESTUARY

MAY to OCTOBER 1968

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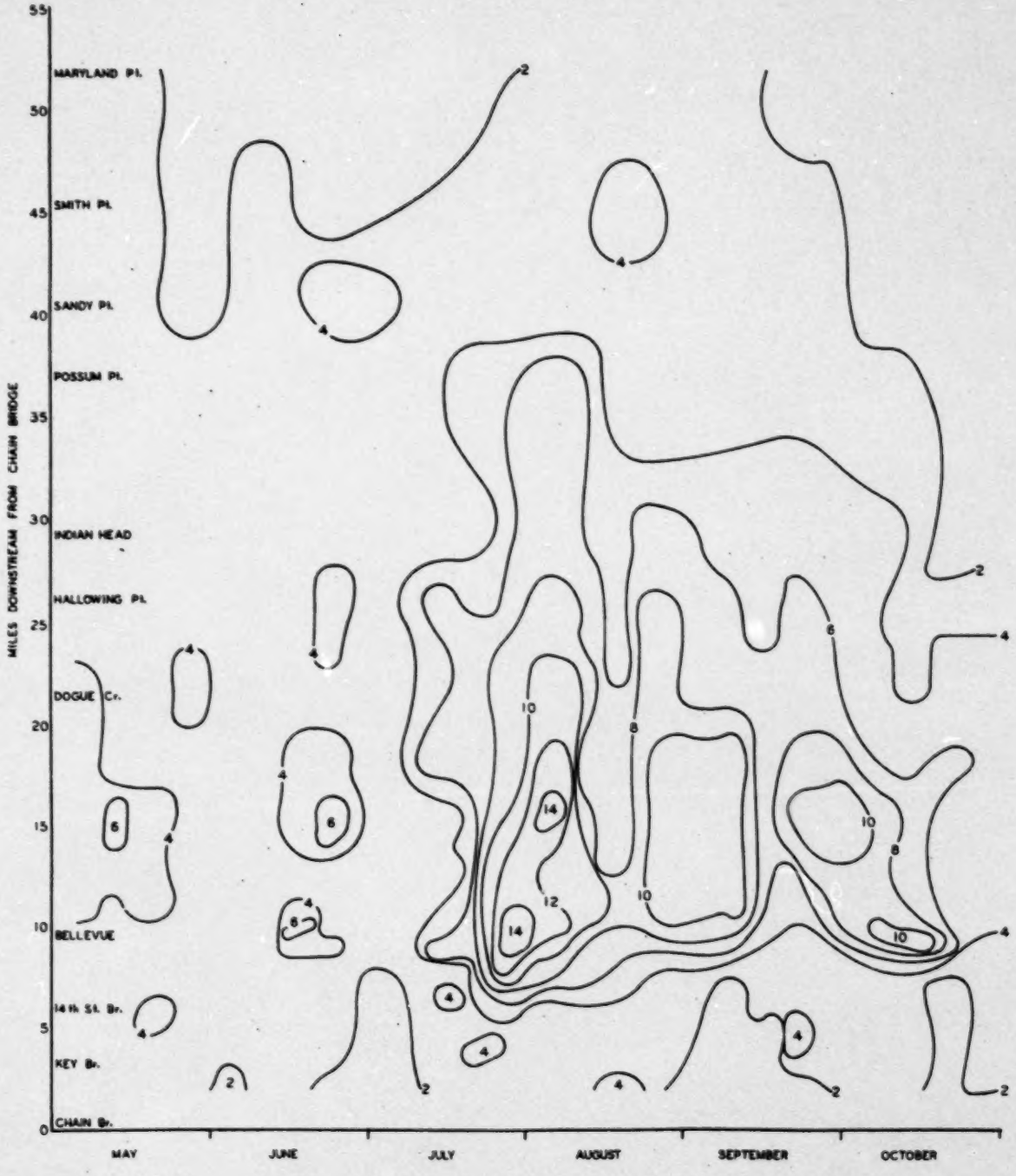

FIGURE II-4

D. Nutrients - Phosphorus and Nitrogen

1. Sources of Nutrients

In 1966, an extensive sampling program was initiated by CTSL to determine the sources, spatial distribution, transport mechanisms, etc., of nutrients in the Potomac River Basin [8]. The delineation of the sources as presented in Tables II-3 and II-4 indicates the following for an average stream flow year:

a. Of the 93,600 lbs. per day of total phosphorus as PO_4 which enter the surface waters of the basin, over 92 percent on the average comes from wastewater discharges.

b. Of the 93,600 lbs. per day of PO_4, 62,000 lbs. per day or 66 percent enter the upper Potomac Estuary from wastewater discharges.

c. The total loading of nitrogen as N to the surface waters of the basin from all sources is about 152,700 lbs. per day, of which 65,300 lbs. per day or 42 percentare from wastewater discharges.

d. About 36 percent of the total nitrogen loading is from wastewater discharges in the upper Potomac Estuary.

Another important aspect of the nutrient problem in the upper estuary is the annual variation in nutrient contribution by the sources. The average monthly loadings from the wastewater discharges in the upper estuary are relatively uniform when compared to the great variations in loadings from the upper Potomac River Basin. As can be seen in Table II-5, the average monthly loading of nitrite-nitrate nitrogen can vary from 17,400 to about 174,800 lbs. per day.

TABLE II-3

AVERAGE TOTAL PHOSPHORUS LOADINGS AS PO_4

Potomac River Basin

Area	In Wastewater Discharges (lbs./day)	From Land and Other Sources (lbs./day)	Total (lbs./day)
Upper Potomac (Above Great Falls)	22,000	5,800*	27,800
Lower Potomac (Below Great Falls)	64,200	1,600**	65,800
Total	86,200	7,400	93,600

* Based on an average flow at Great Falls of 10,800 cfs and a background concentration of 0.1 mg/l of Phosphorus as PO_4 or a daily yield of 0.51 lbs./sq.mile/day.

** Based on a yield of 0.51 lbs./sq.mile/day for the lower portion of the basin with a drainage area of 3,100 square miles.

TABLE II-4

AVERAGE TOTAL NITROGEN LOADINGS AS N
Potomac River Basin

Area	In Wastewater Discharges		From Land and Other Sources		Total
	TKN (lbs./day)	NO_2+NO_3 (lbs./day)	TKN (lbs./day)	NO_2+NO_3 (lbs./day)	(TKN + NO_2+NO_3) (lbs./day)
Upper Potomac (Above Great Falls)	11,000	Insignificant	21,000*	48,000**	80,000
Lower Potomac (Below Great Falls)	54,300	Insignificant	5,600*	12,800**	72,700
Total	65,300	Insignificant	26,600	60,800	152,700

* Based on an average flow at Great Falls of 10,800 cfs and a background concentration of 0.36 mg/l of TKN as N or a yield of 1.6 lbs./sq.mile/day for the lower Potomac.

** Based on a predicted total nitrogen loading at Great Falls of 80,000 lbs./day minus the TKN contribution or a yield of 4.15 lbs./sq.mile/day for the lower Potomac.

TABLE II-5

PREDICTED AVERAGE MONTHLY NUTRIENT LOADINGS

POTOMAC RIVER

NEAR WASHINGTON, D. C.

Month	Flow* (cfs)	TPO_4 as PO_4 (lbs./day)	TKN as N (lbs./day)	NO_2+NO_3 as N (lbs./day)
Jan.	13,590	26,130	9,820	88,600
Feb.	16,630	33,151	11,610	121,000
March	21,090	43,870	14,140	174,800
April	20,000	41,210	13,530	161,000
May	14,450	28,090	10,340	97,400
June	8,688	15,420	6,780	44,370
July	5,456	8,900	4,610	21,600
Aug.	6,113	10,180	5,060	25,760
Sept.	4,747	7,560	4,100	17,400
Oct.	6,310	10,580	5,200	27,060
Nov.	6,575	11,100	5,380	28,800
Dec.	9,886	17,950	7,540	54,200
Average	11,128	21,180	8,175	71,830

* Average monthly flows adjusted for diversions.

These variations are more propounced when daily values are considered. For example, in August of 1966, with a flow of about 540 cfs entering the estuary less than 1000 lbs. per day of phosphorus as PO_4 and NO_2+NO_3 as N entered the upper estuary from the upper Potomac River Basin, while in February with a flow greater than 40,000 cfs, about 48,000 and 354,000 lbs. per day of phosphorus and NO_2+NO_3 nitrogen, respectively, entered the estuary.

The transport mechanisms and rates for the varying nutrient loadings in the Potomac Estuary are currently under investigation by CTSL.

2. Nutrient Concentrations in the Estuary

As presented in Figure II-5, the total Kjeldahl nitrogen (TKN)* concentrations are the highest in the reach from the 14th Street Bridge (River Mile 6.0) to Indian Head (River Mile 29.0). In the upper estuary near Woodrow Wilson Bridge (River Mile 11.8), concentrations of 3.0 mg/l and greater were observed in July and August.

The end product of the oxidation of TKN is nitrite-nitrate nitrogen. As shown in Figure II-6, the high concentrations of NO_2+NO_3 (above 1.5 mg/l) are farther downstream and there is a lag in time when compared to the level of TKN in the estuary. The significance of this oxidation process is discussed later in this report.

*TKN parameter includes both organic and NH_3 nitrogen.

TKN as N ISOPLETH

(mg/l)

UPPER POTOMAC ESTUARY

MAY to OCTOBER 1968

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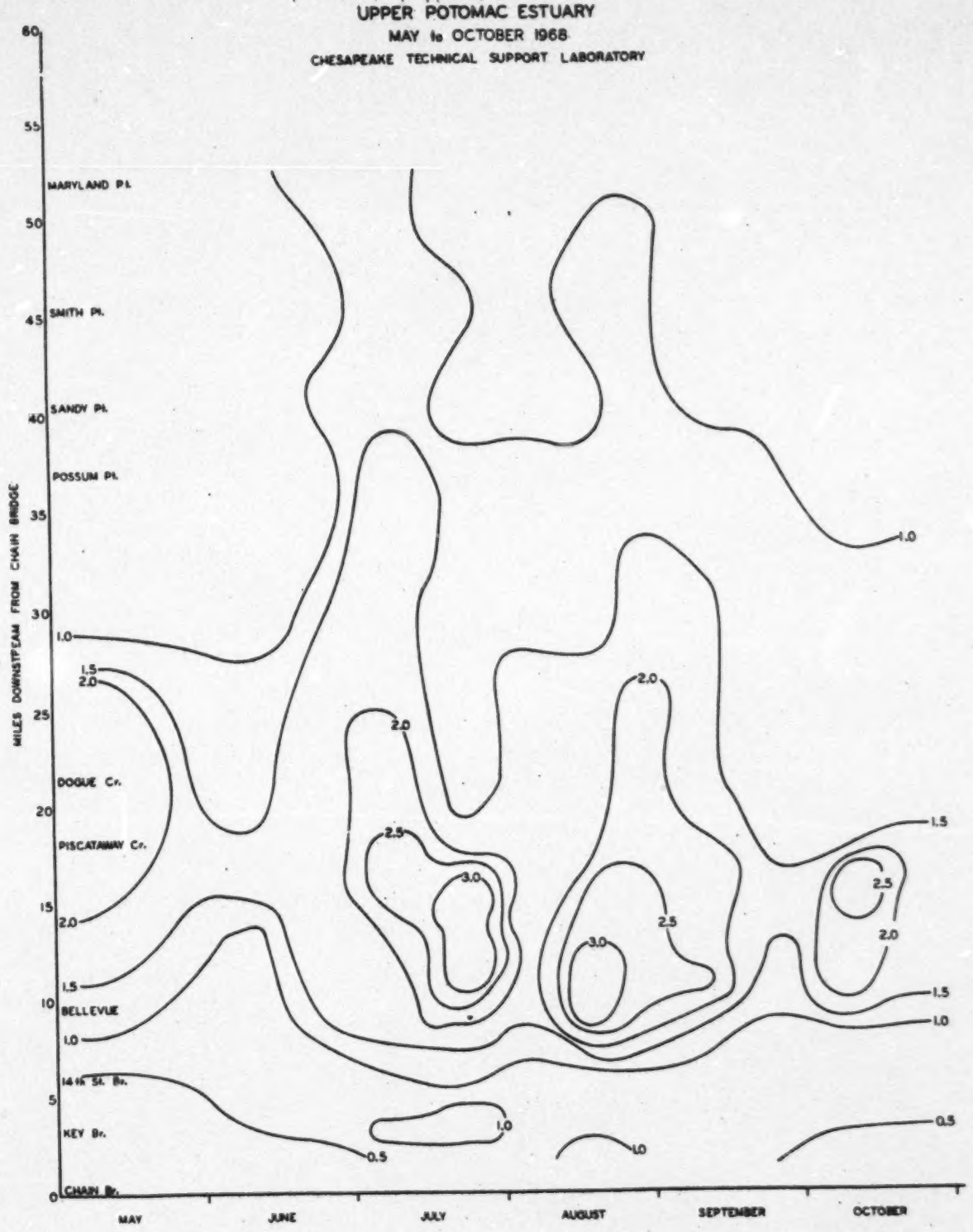

FIGURE II-5

$NO_2 + NO_3$ as N ISOPLETH
(mg/l)
UPPER POTOMAC ESTUARY
MAY to OCTOBER 1968
CHESAPEAKE TECHNICAL SUPPORT LABORATORY

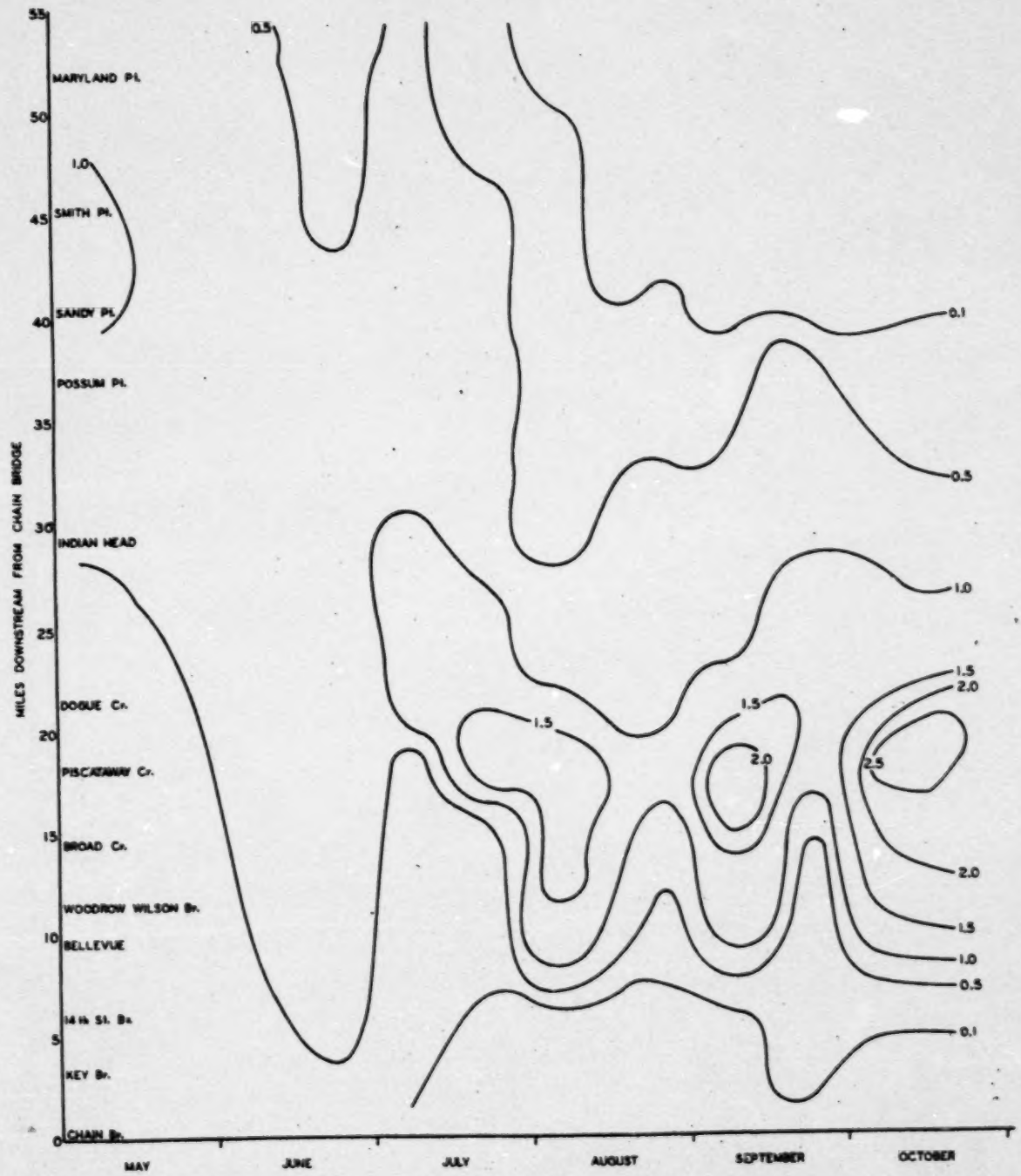

FIGURE II-6

The TKN and NO_2+NO_3 concentrations of the water entering the estuary during the months of July through October were about 0.7 and less than 0.1 mg/l, respectively.

The phosphorus concentrations were similar to TKN levels during the period from May through October (Figure II-7). During the months of August, September and October, the concentration of phosphorus was 2.0 mg/l and greater in the vicinity of Woodrow Wilson Bridge.

The concentration of phosphorus in the waters entering the estuary varied from 0.1[illegible] to 0.423 mg/l.

E. Algal Standing Crop

Using chlorophyll "a" as a measure of algal standing crop, the isopleth as presented in Figure II-8 indicates that there was a widespread bloom* in the Potomac Estuary during the summer months of 1968. For the month of August, chlorophyll levels of 150 µg/l and greater were observed from Bellevue (River Mile 9.7) to Hallowing Point (River Mile 26.0).

During the months of May and June, the predominant algal species in the upper estuary was Chlamydomonas sp., a green flagellate. During the months of July through September the predominant species was Anacystis cyanea, a coccoid blue-green algae. During the month of November, the predominant phytoplankton was Chlorella, a coccoid green algae.

*When chlorophyll levels are 50 µg/l and greater, bloom conditions are assumed to exist.

TOTAL P as PO_4 ISOPLETH

(mg/l)

UPPER POTOMAC ESTUARY

MAY to OCTOBER 1988

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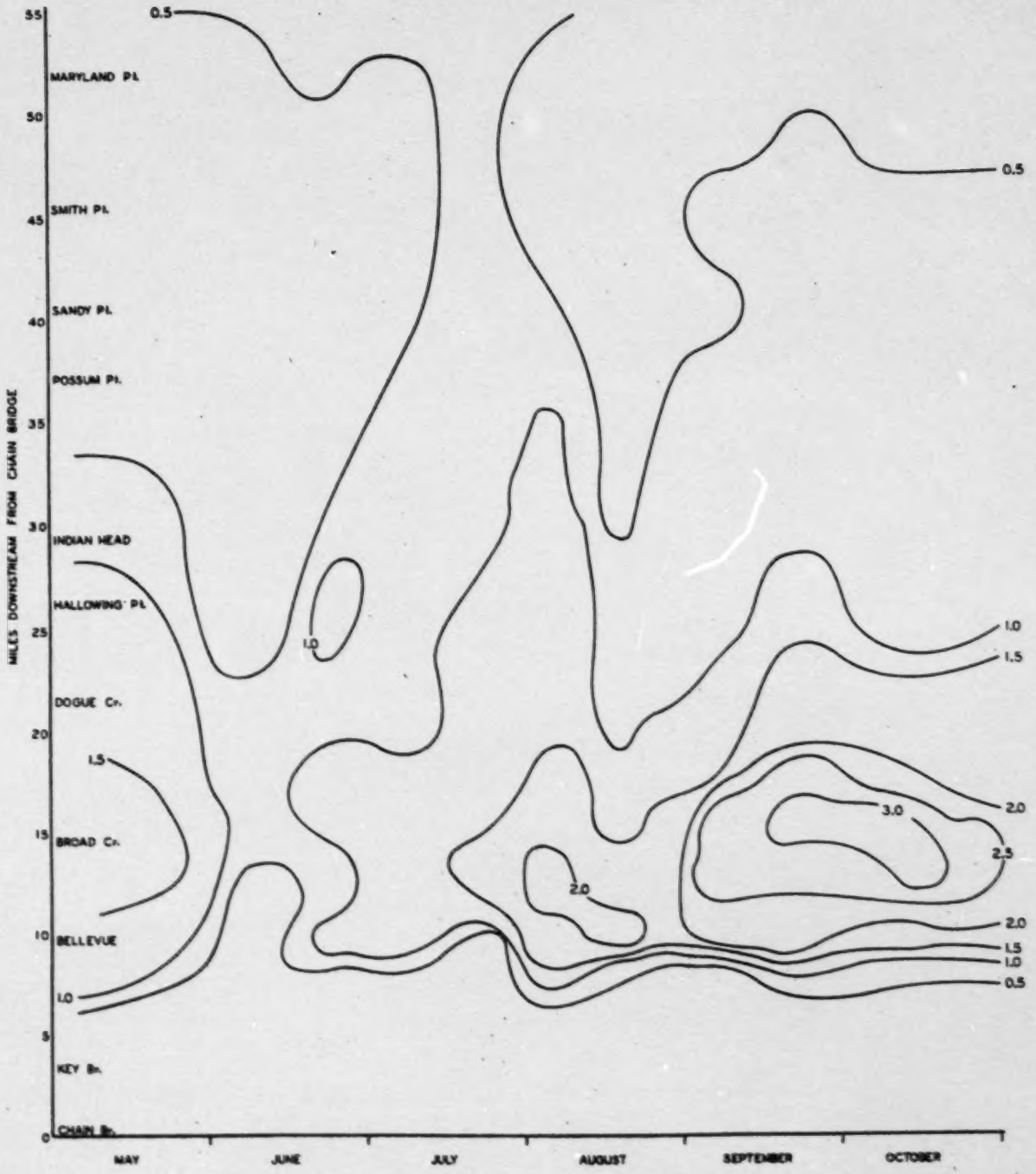

FIGURE II-7

CHLOROPHYLL ISOPLETH

(µg/l)

UPPER POTOMAC ESTUARY

MAY to OCTOBER 1968

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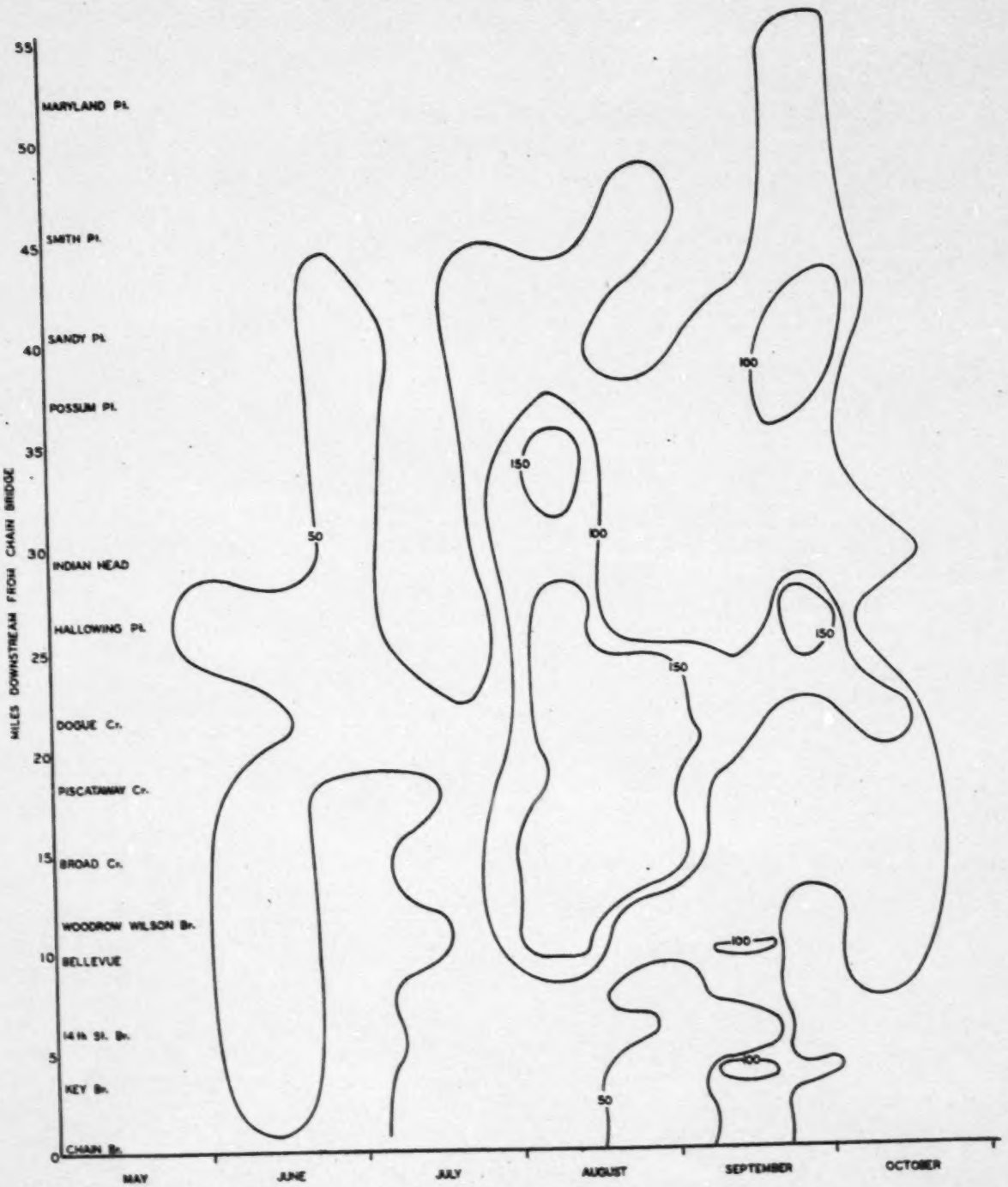

FIGURE II-8

CHAPTER III

NUTRIENT-ALGAL RESPONSE AND ENVIRONMENTAL REQUIREMENTS

As presented in Figure II-8, the chlorophyll levels during the months of June through October 1968 were generally greater than 50 μg/l for approximately 50 miles of the upper estuary. Similar chlorophyll levels were also observed in the upper estuary during summer months of 1965, 1966 and 1967.

In an effort to determine rate limiting concentrations of various measurable nutrients, which if controlled could alleviate the eutrophic conditions in the upper Potomac Estuary, an analysis of data from intensive surveys and routine monitoring stations has been undertaken at CTSL. Statistical analyses were also made on other areas for comparison as presented in Table III-1.

In the analyses, the following parameters were investigated:

1. Total Phosphorus
2. Inorganic Phosphorus
3. NO_2-Nitroge.
4. NO_3-Nitrogen
5. TKN-Nitrogen
6. NH_3-Nitrogen
7. Temperature
8. Secchi Disc (measure of light extinction)
9. Nitrogen/Phosphorus Ratio
10. Salinity
11. TOC

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TABLE III-1

NUTRIENT-CHLOROPHYLL DATA SOURCES

Data Source Number	Water Course	Year Collected	Agency C B I
I	Potomac Estuary Middle-lower	1965-1966	Johns Hopkins Univ.
II	Potomac Estuary a - upper b - middle c - lower	1965-1966	CFS, FWPCA
III	Potomac Estuary a - upper b - middle c - lower embayments	1967-1968	CFS, FWPCA
IV	Patuxent Estuary a - upper-middle	1968	CFS, FWPCA
V	James Estuary		Va. Institute of Marine Science
VI	Upper Chesapeake Bay a - Northeast River b - Upper Bay	1968	CFS, FWPCA
VII	Middle Chesapeake Bay	1967-1968	CFS, FWPCA

By grouping the data, the physical effects of fresh water inflow, channel-depth, tidal velocity, salinity, etc., on the algal standing crop were also investigated.

Preliminary results of the statistical analyses for the Potomac Estuary and the other eutrophic areas are presented below.

A. Phosphorus

A nutrient which has been often related to nuisance algal blooms is phosphorus. To determine if increase in algal growths in the Potomac Estuary is related to the high phosphorus levels, analyses of the data from the years 1965-1968 primarily for the summer conditions were made.

Figure III-1 is a graphical presentation of the chlorophyll-phosphorus relationship developed by plotting the mean phosphorus* versus the mean chlorophyll levels for the various areas indicated in Table III-1. From the graphical presentation, it appears that when the phosphorus level is below 0.6 mg/l growth-dependent conditions occur (i.e., under these conditions, the chlorophyll level or standing stock is directly proportional to the phosphate concentration present). Above 0.6 mg/l of phosphate, the chlorophyll appears to be constant and independent of the phosphorus

*In this report all phosphorus concentrations are given as total phosphorus as PO_4 unless stated otherwise.

CHLOROPHYLL – TOTAL PHOSPHORUS CONCENTRATIONS

SUMMER CONDITIONS

FOR VARIOUS AREAS OF THE CHESAPEAKE BAY SYSTEM

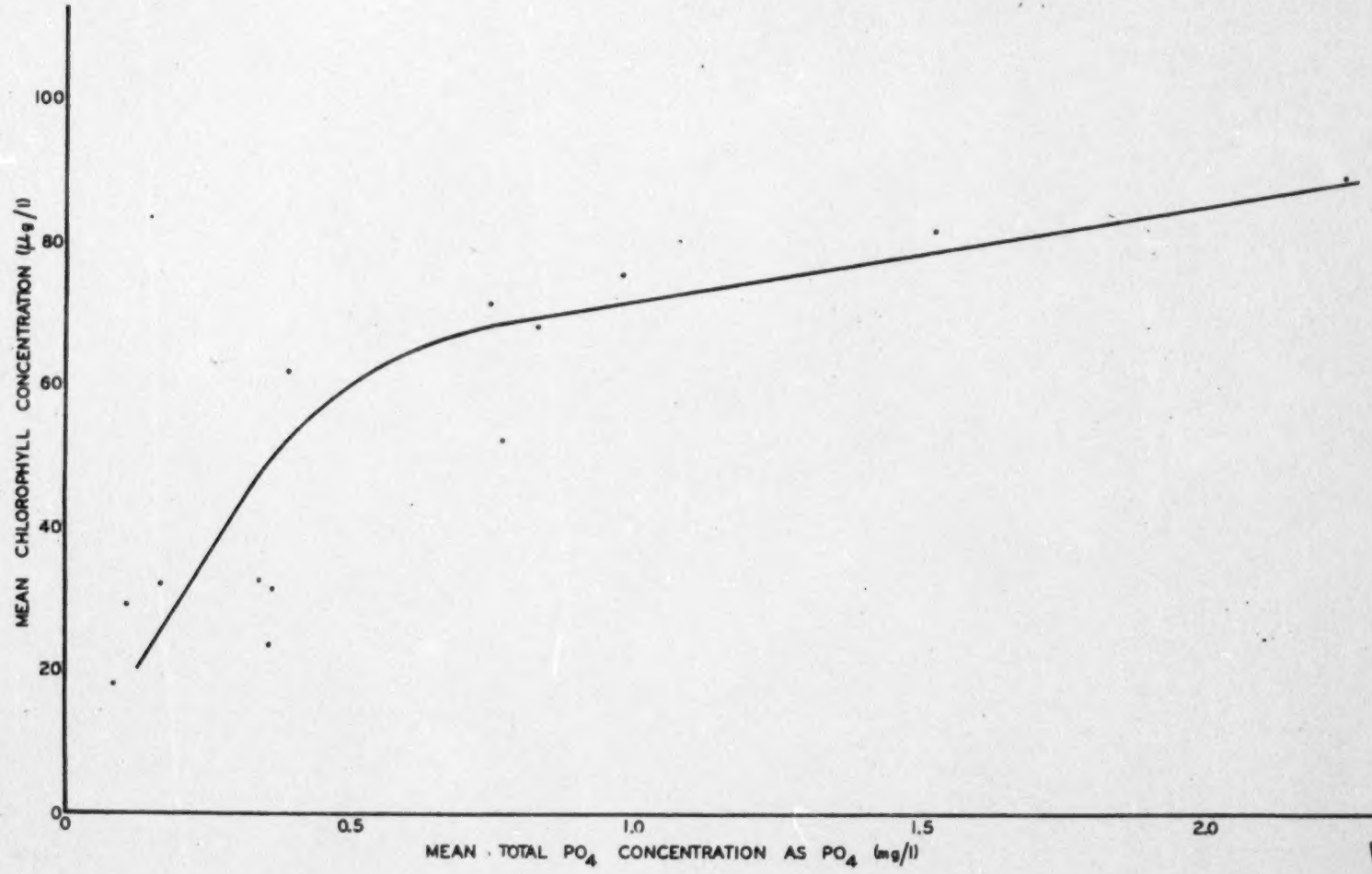


FIGURE III-1

concentration.* Similar observations with regards to growth response have been made by Borchardt and Azad [9] in studying phosphorus uptake by algal cultures in the laboratory.

In Figure III-2 is exhibited chlorophyll inorganic phosphorus concentration for the 1966 summer intensive survey by CTSL. Sampling stations in the Potomac Estuary are shown in Figure I-1. The relationship is very similar to that of the entire Chesapeake Bay system, as presented in Figure III-1.

From the relationships in Figures III-1 and III-2, it appears that nuisance algal bloom (above 50 μg/l of chlorophyll) can be reduced significantly in the Potomac Estuary if the total phosphorus level is maintained below 0.39 mg/l as PO_4 or in terms of inorganic phosphorus, 0.30 mg/l. This is assuming that all other algal growth conditions are favorable.

B. Nitrogen

The analyses of nitrogen-algal relationships are more complex than phosphorus-algal responses in that the predominant form of nitrogen entering the estuary can be either NH_3, NO_3 or organic. During spring high flows, the nitrate-nitrogen form, primarily from land runoff, is the most abundant.

Coupled to varying forms of nitrogen entering the estuary are the biochemical dynamics of the nitrogen cycle itself. During the

*Above this concentration, "luxury uptake" of phosphorus occurs.

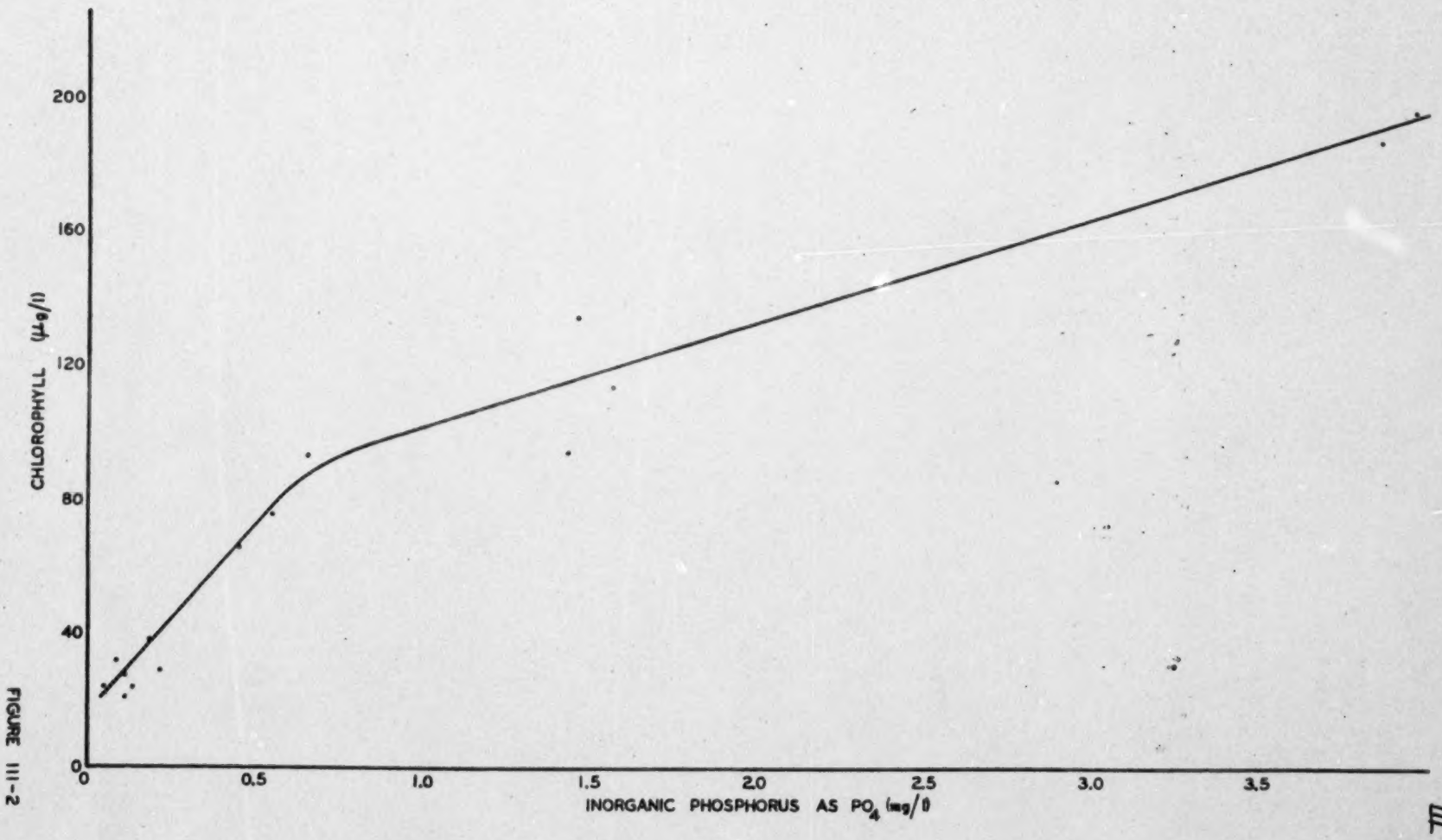

CHLOROPHYLL - INORGANIC PHOSPHORUS CONCENTRATIONS
POTOMAC ESTUARY
INTENSIVE SURVEY - 1966
CHLOROPHYLL (µg/l)
200
160
120
80
40
0
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
INORGANIC PHOSPHORUS AS PO4 (mg/l)

FIGURE III-2

summer months, most of the ammonia and some of the organic nitrogen from wastewater discharges are oxidized to nitrate-nitrogen as exemplified by the August 1968 survey. (See Figure III-3.) The nitrate form is then taken up by the algae and converted into organic nitrogen as part of the cell.

Mass balances of the various nitrogen fractions, phosphorus, and chlorophyll were made utilizing the data from the intensive surveys. The balances, or more specifically, instantaneous loading rates, were calculated by the formulation as presented below:

$$P = L \times A \times C \times F$$

where

P = Loading rate in a given cross section (lbs./linear ft.)

L = One linear foot of estuary (ft.)

A = Cross section area (ft^2)

C = Average concentration of parameter in cross section (mg/l)

F = A conversion factor

The dynamics of the nitrogen system are shown in Figure III-4, which is a graphical presentation of the instantaneous loading rates for the August 19-22, 1968, survey. From River Mile 0.0 to River Mile 10.0, there is a rapid increase in TKN and NH_3 loading. Starting at River Mile 2.0, the nitrate loading starts to increase with a maximum loading rate at River Mile 20.0 which corresponds to the minimum loading rate of NH_3 downstream from the wastewater discharge.

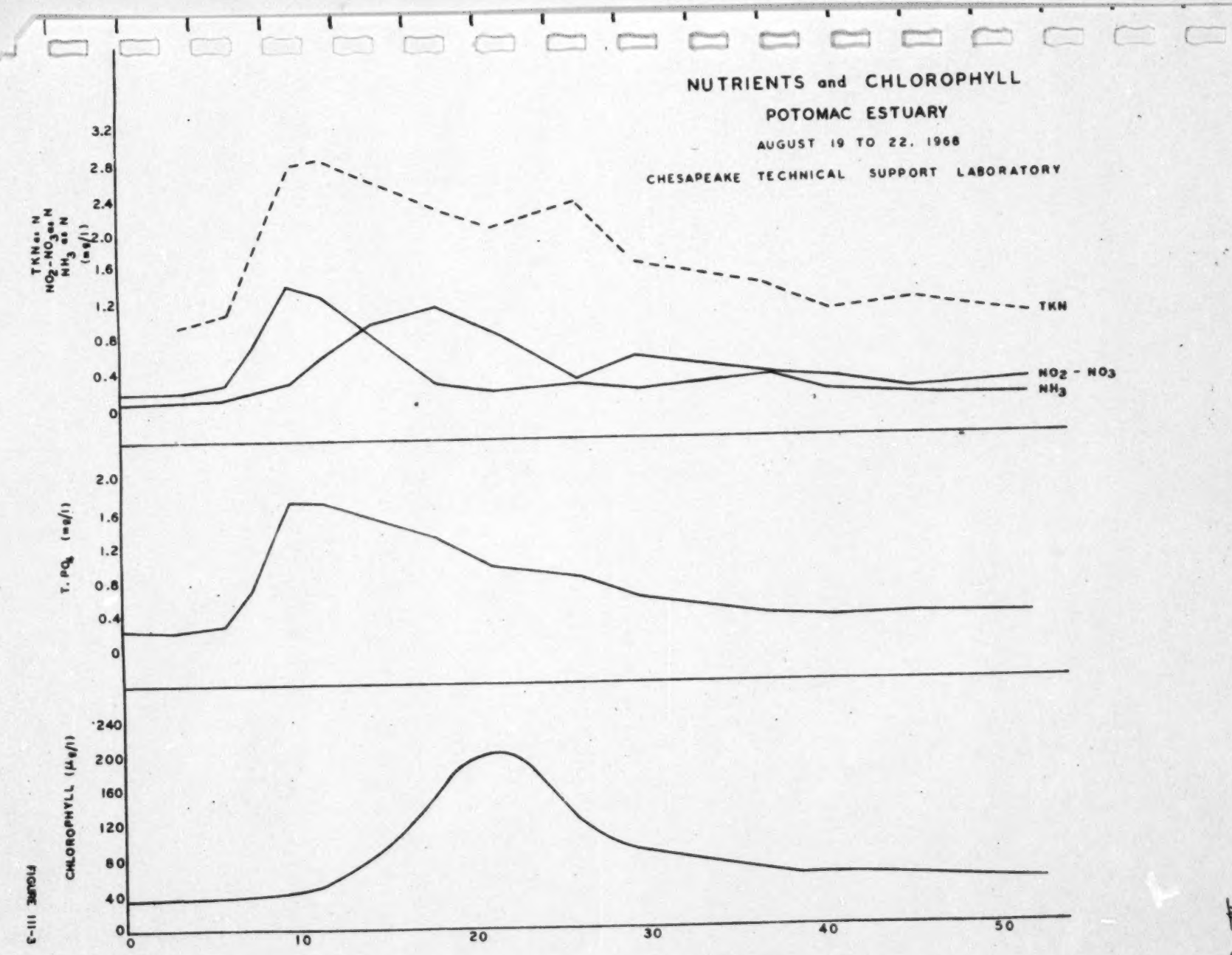

NUTRIENTS and CHLOROPHYLL
POTOMAC ESTUARY
AUGUST 19 TO 22, 1968
CHESAPEAKE TECHNICAL SUPPORT LABORATORY
TKN as N
NO2-NO3 as N
NH3 as N (mg/l)
3.2
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0
TKN
NO2 - NO3
NH3
T. PO4 (mg/l)
2.0
1.6
1.2
0.8
0.4
0
CHLOROPHYLL (µg/l)
240
200
160
120
80
40
0
0
10
20
30
40
50

FIGURE III-3

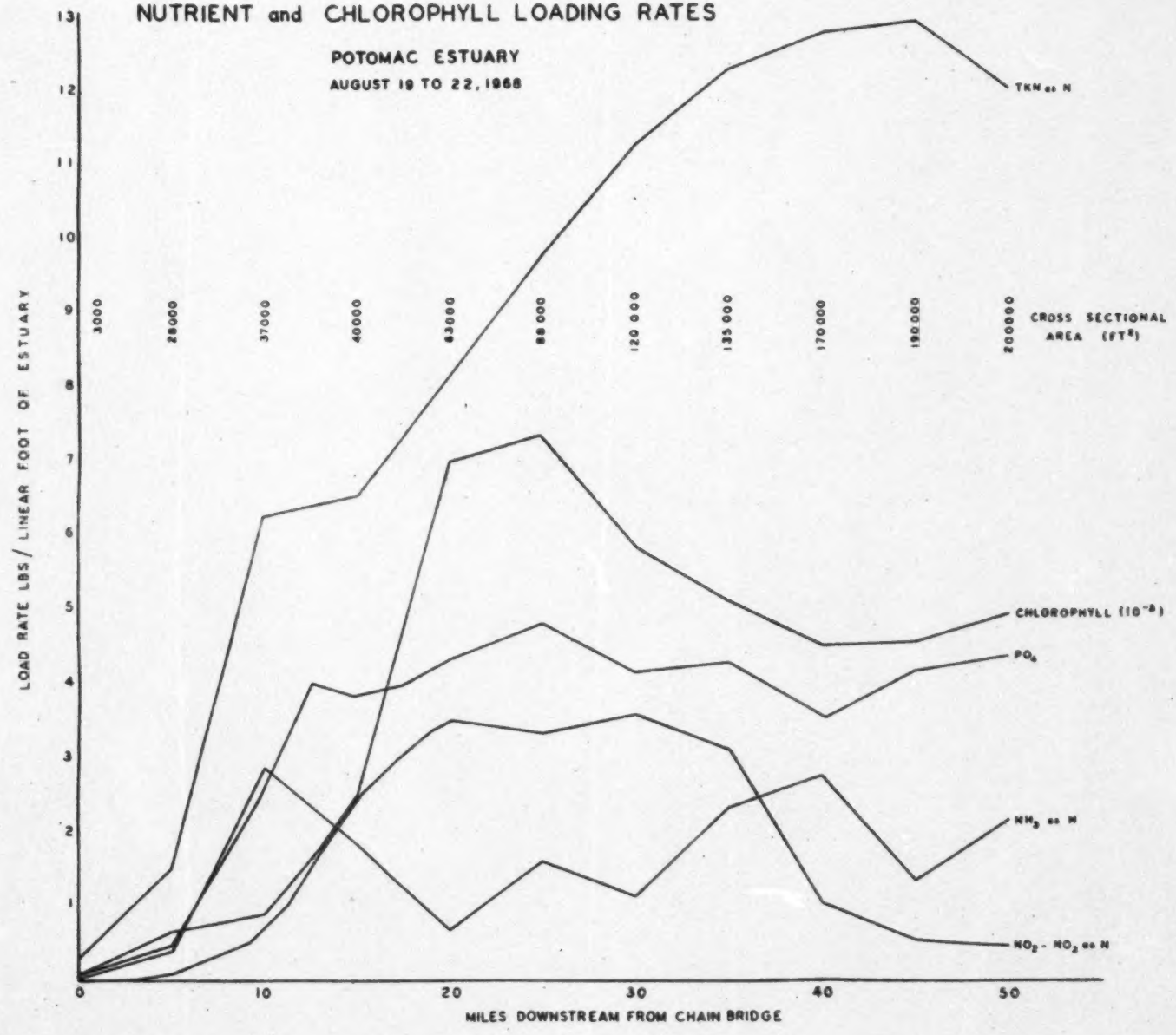


FIGURE III-4

III-9

In the reach from River Mile 30 to 50, the nitrate loading decreases to less than 1 lb. per linear foot. This decrease in nitrate is attributed to utilization by the algal cells.

The mass balances as presented in Figure III-3 also indicate that most of the phosphorus moves downstream. This constant loading rate for phosphorus corroborates the works of Hayes [10] in which he stated that the recycling time of inorganic PO_4 by phytoplankton and bacterial cells is very short, less than one day. Mass balances for other surveys indicate similar downstream movement except in the upper estuary during periods of low flow. Under low flow conditions, the concentration of phosphates is often above 2.0 mg/l and considerable depositions occur. Deposition to the bottom muds occurs at lower phosphorus levels in the middle and lower portions of the estuary as supported by data from recent Potomac Estuary sediment surveys; however, the rate of deposition is much less at low concentrations.

In Figure III-5 is a graphical presentation of the nitrate nitrogen-chlorophyll concentrations for the same conditions as in Figure III-1 for phosphorus. When the areas with phosphorus concentrations of less than 0.39 mg/l are noted, the relationship between chlorophyll and inorganic nitrogen appears to be significant.

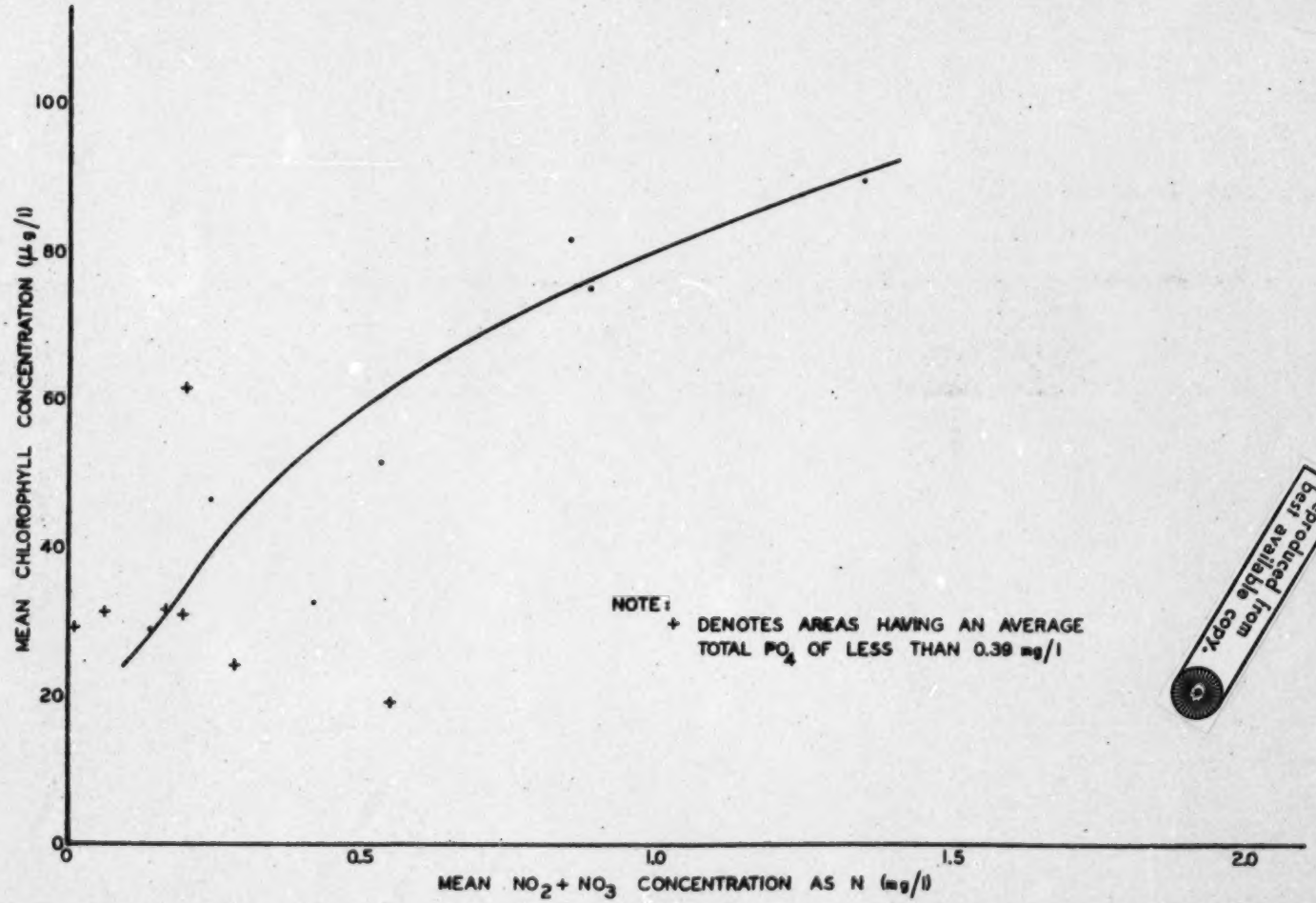
For the 1966 and 1968 intensive surveys in the Potomac Estuary, the relationships of chlorophyll to NO_2+NO_3 nitrogen are more pronounced, as can be seen in Figure III-6. Moreover, the relationship is linear with no point of "luxury uptake" as with phosphorus.

Using the 50 μg/l of chlorophyll level as for phosphorus and the relationships in Figures III-5 and III-6, maintaining of concentrations of less than 0.35 mg/l of NO_2+NO_3 nitrogen as N

CHLOROPHYLL – INORGANIC NITROGEN CONCENTRATIONS

SUMMER CONDITIONS

FOR VARIOUS AREAS OF THE CHESAPEAKE BAY SYSTEM



NOTE:
+ DENOTES AREAS HAVING AN AVERAGE TOTAL PO_4 OF LESS THAN 0.39 mg/l

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FIGURE III-5

CHLOROPHYLL – INORGANIC NITROGEN CONCENTRATIONS

POTOMAC ESTUARY

INTENSIVE SURVEYS – 1966 & 1968

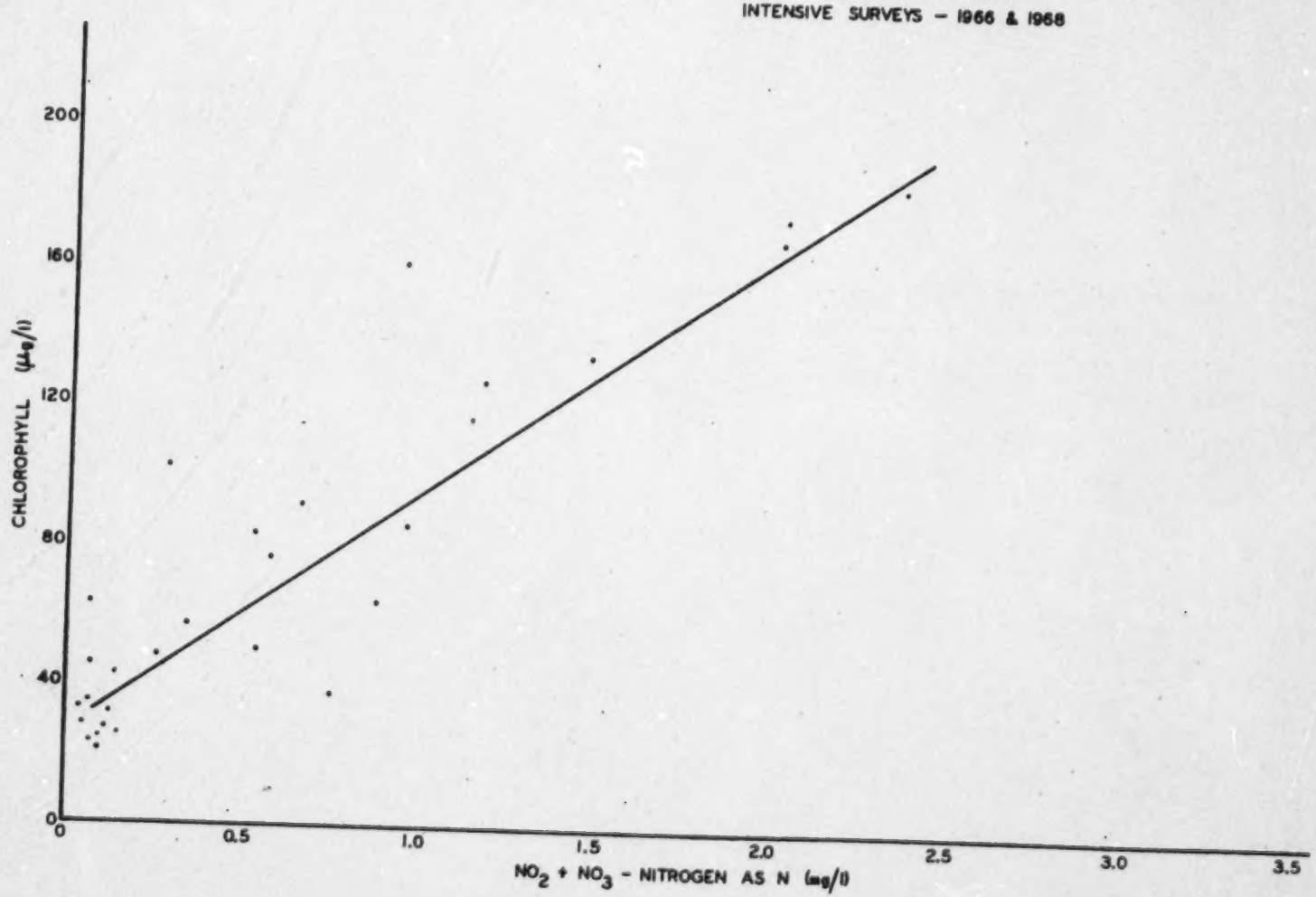

FIGURE III-6

III-12

should alleviate nuisance phytoplankton conditions in the Potomac Estuary. Again, this is assuming that no other vital system is rate-limiting.

Also, in analyzing the data from the 1965-1968 Potomac Estuary surveys and monitoring stations in the Chesapeake Bay, the following observations have been made:

1. During the periods of low flow in the summer months, high chlorophyll concentrations and high NO_2+NO_3 (end product of the oxidation of NH_3) usually occur in the same reach of the upper Potomac Estuary. This suggests that nitrogen could be limiting the total standing crop; however, more studies are needed to determine the significance of this simultaneous occurrence.

2. In the lower part of the estuary, and in the Chesapeake Bay, a significant relationship between TKN and chlorophyll was established for summer conditions. Mass balances in the Potomac Estuary for 1966 and 1968 indicate a continued increase in TKN loading rates in the upper 30 to 40 miles of the estuary.

3. In waters seaward from areas with high chlorophyll levels, nitrate levels are usually quite low during the summer months. The low nitrate levels coupled with high TKN concentrations suggest that algal cells are utilizing the nitrate form of nitrogen readily and converting it to TKN.

4. Mass balances from the 1968 Potomac Estuary data obtained in August indicate that from River Mile 15.0 to 40.0 the loading

rate for TKN was increased from about 6.0 to over 13.0 lbs. per linear foot. (See Figure III-4.) This suggests that fixation of nitrogen from the atmosphere was significant. If all this TKN was from nitrogen fixation, the amount of nitrogen was about equivalent to that from the wastewater discharge loadings.

C. Other Considerations

1. Stream Flow

In the Potomac and the Patuxent* estuaries, the effect of a large increase in fresh water flow on reducing chlorophyll has been observed on numerous occasions.

Reduction in chlorophyll levels by a sudden increase in stream flow is attributed partially to dilution, dispersion and seaward displacement. In the Patuxent River especially, suspended sediments appeared to remove some of the algal growth by accelerating the settling of the cells.

During September 1966, after the lowest flow of record entering the Potomac Estuary (150 cfs), chlorophyll levels of over 200 $\mu g/l$ were reduced to less than 25 $\mu g/l$ by a rapid rise in flow to over 27,000 cfs. Similar observations were made in the Patuxent during July of 1968.

2. Temperature, Solar Radiation, and Light Extinction

The effects of temperature and light conditions on algal growth have been well studied in the field and in the laboratory [11] [12].

*The Patuxent River Basin, lying within the State of Maryland, is about one-tenth the size of the Potomac.

Average temperatures in the Potomac Estuary for the months of May through October range from 18°C to 28°C. When the temperature as presented in Figure II-1 is compared with chlorophyll "a" as shown in Figure II-8, it can be seen that temperatures above 20°C appear to be conducive to supporting extensive algal growths in the Potomac Estuary.

Analyses of light intensity data such as turbidity and Secchi disc readings which could affect the algal standing crop have indicated no statistically significant relationship.

3. Other Environmental Parameters

Many other environmental parameters such as heavy metals, salinity, micronutrients, etc., which may have some effect on algal growths are either currently under study or have been incorporated into the 1971-75 program plan of the Middle Atlantic Region, FWPCA.

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CHAPTER IV

ORGANIC LOADINGS IN THE UPPER AND MIDDLE ESTUARIES

The BOD concentrations in the upper estuary as shown in the isopleth in Figure II-4 are greatly increased by wastewater discharges from the Washington metropolitan area. To aid in the design of treatment facilities, a study of the magnitude and significance of each of the sources of BOD and other organic loadings as presented in Chapter II was undertaken.

In Figure IV-1 the measured 5-day BOD and TOC concentrations during the intensive survey of August 19 to 22, 1968, are shown. The corresponding nutrient and chlorophyll concentrations are presented in Figure III-2.

The major difficulty in quantitating the significant sources of BOD is that the 5-day BOD determination is a composite of all four sources. The discussion that follows is an attempt to quantitate the various sources of 5-day BOD in the upper and middle estuary.

A. Algal Carbonaceous and Nitrogenous BOD

During the growth phase, phytoplankton have been shown to have considerable diurnal effect on the oxygen balance as a result of photosynthetic oxygen production during the day and the "take-up" of oxygen by respiration at night [13] [14]. In algal

5-DAY BOD DELINEATION & TOC - DO PROFILES

POTOMAC ESTUARY

AUGUST 19-22, 1968

CHESAPEAKE TECHNICAL SUPPORT LABORATORY

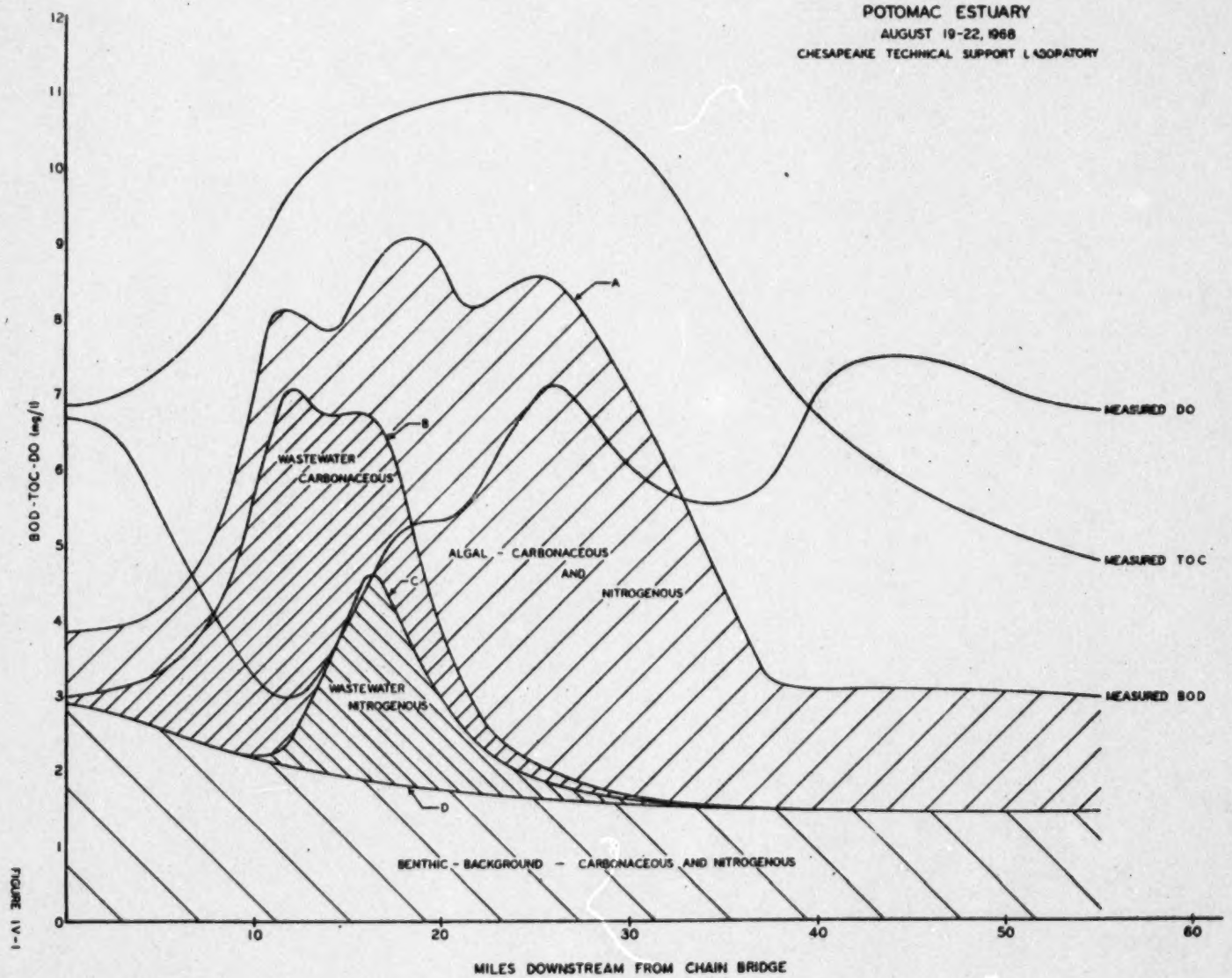

FIGURE IV-1

IV-2

cells, Bain [15] has computed the theoretical ultimate oxygen demand* of a phytoplankton growth having a concentration of 1.0 μg/l of chlorophyll to be about 0.23 mg/l if all carbon and nitrogen were oxidized.

To determine the contribution of the massive phytoplankton growths to BOD in the Potomac Estuary, statistical studies were made on data from sampling stations in the lower Potomac and Chesapeake Bay receiving no significant wastewater discharges. The following relationship was developed for the lower estuary:

$$BOD = 1.5 + 0.03\ Chloro$$

where

BOD = 5-day BOD at mid-channel depths (mg/l)

Chloro = chlorophyll concentration at the water surface (μg/l)

Further analysis utilizing TOC data indicated that most of the algal contribution to BOD was in the form of carbon. For the lower Potomac Estuary, the following relationship was established for summer conditions:

$$BOD = 2.0 + 0.68\ TOC$$

where

BOD = 5-day BOD at mid-channel depth (mg/l)

TOC = total organic carbon at mid-channel depth (mg/l)

*Ultimate oxygen demand [10] consists of the sum of the carbonaceous and nitrogenous BOD as given below:

$$UOD = 2.67\ C + 4.57\ N$$

where

C = unoxidized carbon

N = unoxidized nitrogen

If a chlorophyll level of 100 µg/l is substituted into first relationship, a BOD of 4.5 mg/l is obtained. This is considerably less than the theoretical total oxygen demand which would be 23.3 mg/l. From the above analysis and the TKN load rate curve in Figure III-3, it appears that oxidation of the organic nitrogen component of wastewater and of phytoplankton cells does not occur very rapidly. Similar observations on the slow remineralization of nitrogen compounds from phytoplankton have been made by Gotterman [17] and Harvey [18].

Using the above two relationships, the amount of 5-day BOD attributed to the algal standing crop was determined. The algal BOD was then subtracted from measured 5-day BOD (curve A) as presented in Figure IV-1 yielding curve B. The maximum contribution from the standing crop was at River Mile 27.0 where the 5-day BOD was about 6.0 mg/l.

B. Wastewater Carbonaceous BOD

The contribution of 5-day carbonaceous BOD from the wastewater discharges was determined by routing the loadings as presented in Table II-1 in a mathematical model of the upper estuary [4]. The fresh water inflow and other model parameters were based on observed conditions during the August 19-22, 1968, survey.

The wastewater carbonaceous BOD contribution was subtracted from curve B to determine curve C in Figure IV-1. With 2770 cfs

of fresh water entering the estuary, the maximum increase from wastewater carbonaceous BOD was about 4.5 mg/l at River Mile 11.0.

C. Wastewater Nitrogenous BOD

On an ultimate oxygen demand basis, the nitrogenous BOD can be expressed as follows:

$$UOD_n = 4.57\ N$$

where

UOD_n = ultimate nitrogenous oxygen demand (mg/l)

N = unoxidized nitrogen (mg/l)

The above expression has been verified in the laboratory and in the field [19] [20].

The amount of nitrification in the 5-day BOD usually is considered to be insignificant. Recent studies by CTSL indicated that in highly nitrified water such as the Patuxent and Potomac, the oxidization of NH_3 in the 5-day BOD determination often begins within the first three days of the test. Moreover, in regression analyses of data from the middle and lower Potomac Estuary, generally free from any wastewater sources, the following relationship was established:

$$BOD = 1.0 + 3.3\ NH_3\text{-}N + 0.03\ Chloro$$

where

BOD_5 = 5-day BOD concentration (mg/l)

NH_3-N = Concentration of NH_3 nitrogen (mg/l)

Chloro = Chlorophyll concentration (μg/l)

The 3.3 constant for NH_3-N is somewhat lower than the theoretical value of 4.57. This difference could be due to NH_3 lost to the atmosphere as suggested by Stratton [21].

When the benthic-background BOD, curve D, as presented in the next section, is subtracted from curve C, the amount of the contribution to 5-day BOD from the nitrification process is obtained (Figure IV-1). The largest difference of 2.5 mg/l between the two curves at River Mile 16.0 vividly demonstrates the contribution of the nitrogenous oxygen demand in the 5-day BOD. The effect of nitrification on DO balance is presented later in this chapter.

D. Benthic-Background Carbonaceous and Nitrogenous BOD

Beginning with 2.8 mg/l at River Mile 0.0 and gradually decreasing to 1.5 mg/l at River Mile 55, a benthic-background BOD (curve D) was developed from measured 5-day BOD. This BOD, which can in part be attributed to sludge deposits, upstream loadings, NH_3 loadings from the bottom deposits, etc., is both carbonaceous and nitrogenous. No attempt has been made to fraction this source.

E. Ultimate Oxygen Demand Comparison

In Figure IV-1, the delineation of BOD clearly demonstrates "how much and where" each of four major sources contributes to the total 5-day BOD in the upper estuary. A somewhat different perspective of the BOD sources is obtained when the UOD sources for

the upper estuary between Chain Bridge and Indian Head (River Mile 29.5) are compared as tabulated below:

Sources	UOD (lbs./day)
Wastewater - carbonaceous	188,000
Wastewater - readily oxidizable nitrogenous (NH_3-N)	125,000
Wastewater - less readily oxidizable nitrogenous (organic-N)	116,000
Algal-carbonaceous and nitrogenous	400,000*
Benthic-background - carbonaceous and nitrogenous	80,000

From the above tabulation, it can be readily seen that the major source of UOD in the upper estuary is from phytoplankton with the sum of wastewater nitrogenous BOD second, wastewater carbonaceous BOD third, and benthic-background fourth.

F. Dissolved Oxygen Balance

A schematic diagram in Figure IV-2 originally presented by Torpey [22] shows the interrelationships of the oxidation of carbonaceous and nitrogenous organic matter, photosynthetic activity of phytoplankton, and dissolved oxygen. In the upper Potomac Estuary, these three biological systems can and do occur simultaneously in

*Based on the amount of 5-day BOD required to increase the BOD 6.0 mg/l in the upper estuary. This value can be considered conservatively low.

A SCHEMATIC DIAGRAM OF
DISSOLVED OXYGEN INTERRELATIONSHIPS
FOR THE THREE
MAJOR BIOLOGICAL SYSTEMS

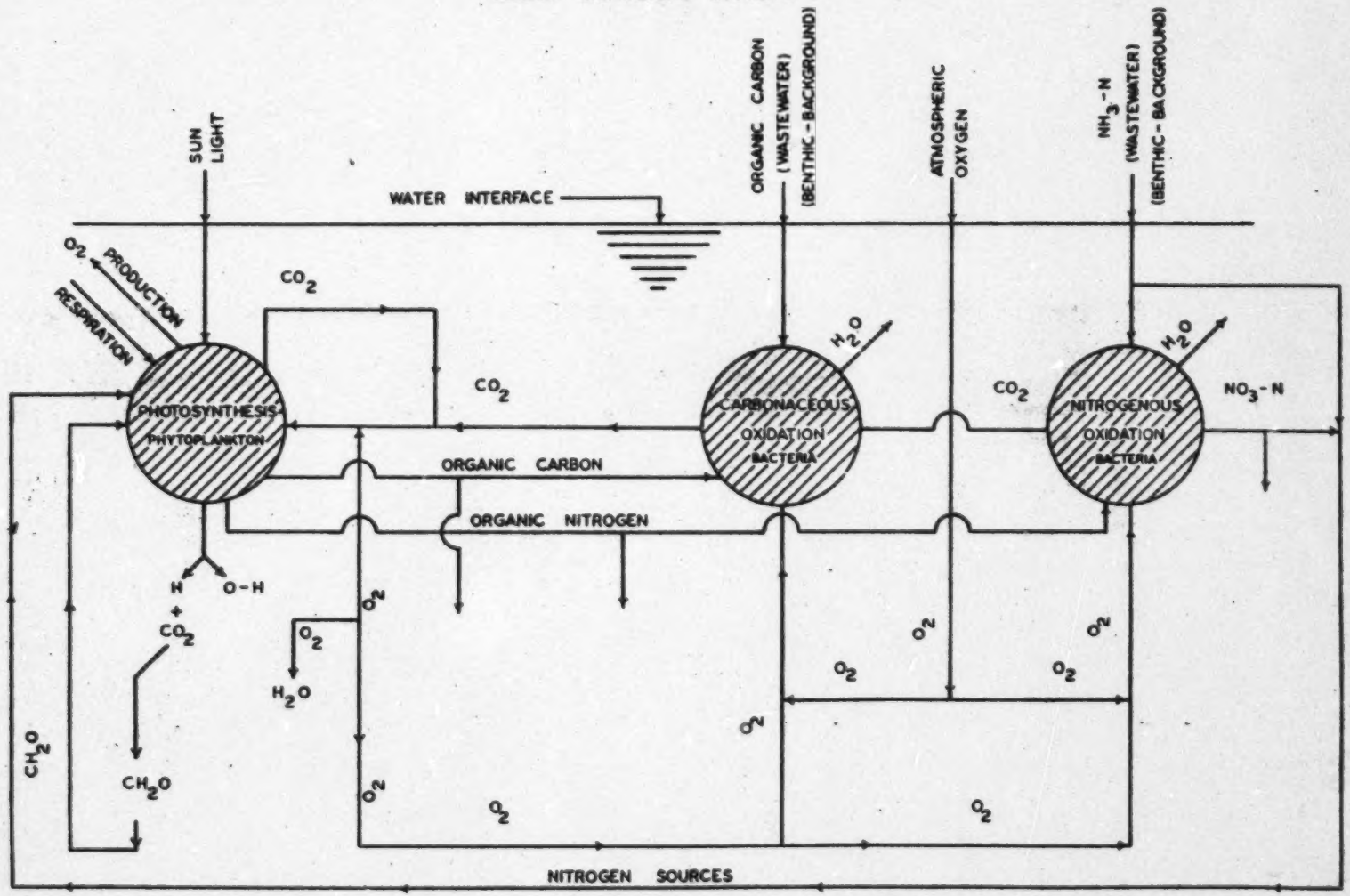

FIGURE IV-2

8-11

the same reach: oxidation of wastewater and algal carbon; oxidation of wastewater NH_3; and photosynthetic activity.

The predominance of one or all of the three systems depends upon such environmental factors as temperature and fresh water inflow. The variation in the DO isopleths as exhibited in Figure II-3 demonstrates the effects of environmental changes on the three systems.

The DO profile for the intensive survey during August of 1968 has three distinct depressions in the upper estuary corresponding to the three biological systems. The first large depression at River Mile 11.5 was mainly due to the oxidation of wastewater carbonaceous BOD. The second depression at River Mile 20 was caused primarily by oxidation of the wastewater nitrogenous BOD. When compared to the nitrification in either the previous or succeeding two-week period, the DO depression in this reach was considerably less as a result of a 50 percent increase in fresh water flow into the estuary during the intensive survey. This reduction in nitrification can be seen clearly in the NO_2+NO_3 isopleth in Figure II-6.

The sharp increase to 7.1 mg/l near River Mile 26 was probably a result of oxygen production by algal cells which were at their highest concentrations in the estuary at this point.

In the reach from River Mile 25 to 35, the 1.5 mg/l DO depression is attributed to decay of the algal cells. A secondary recovery in DO towards saturation values begins at River Mile 35.

CHAPTER V

CURRENT AND PROPOSED INVESTIGATIONS

As indicated in Chapters III and IV, the four major areas currently being studied by CTSL in regard to the Potomac Estuary are as follows:

1. Nutrient-algal relationships,
2. Role of nitrification in DO balance,
3. Nutrient transport mechanisms and rates, and
4. Dispersion.

The data and interpretations presented in this report are to provide a basis for current planning of waste treatment facilities to achieve water quality standards. Studies will be more extensively developed in four separate reports covering each of these areas.

Three field studies which are to be initiated in the near future are:

1. Rate of algal carbon fixation and oxidation,
2. Nutrient-algal rate limiting studies, and
3. Nutrient exchange rates with sediments.

The four current and three planned studies are all designed to provide data for the development of a comprehensive plan for water quality management for the Potomac Estuary.

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